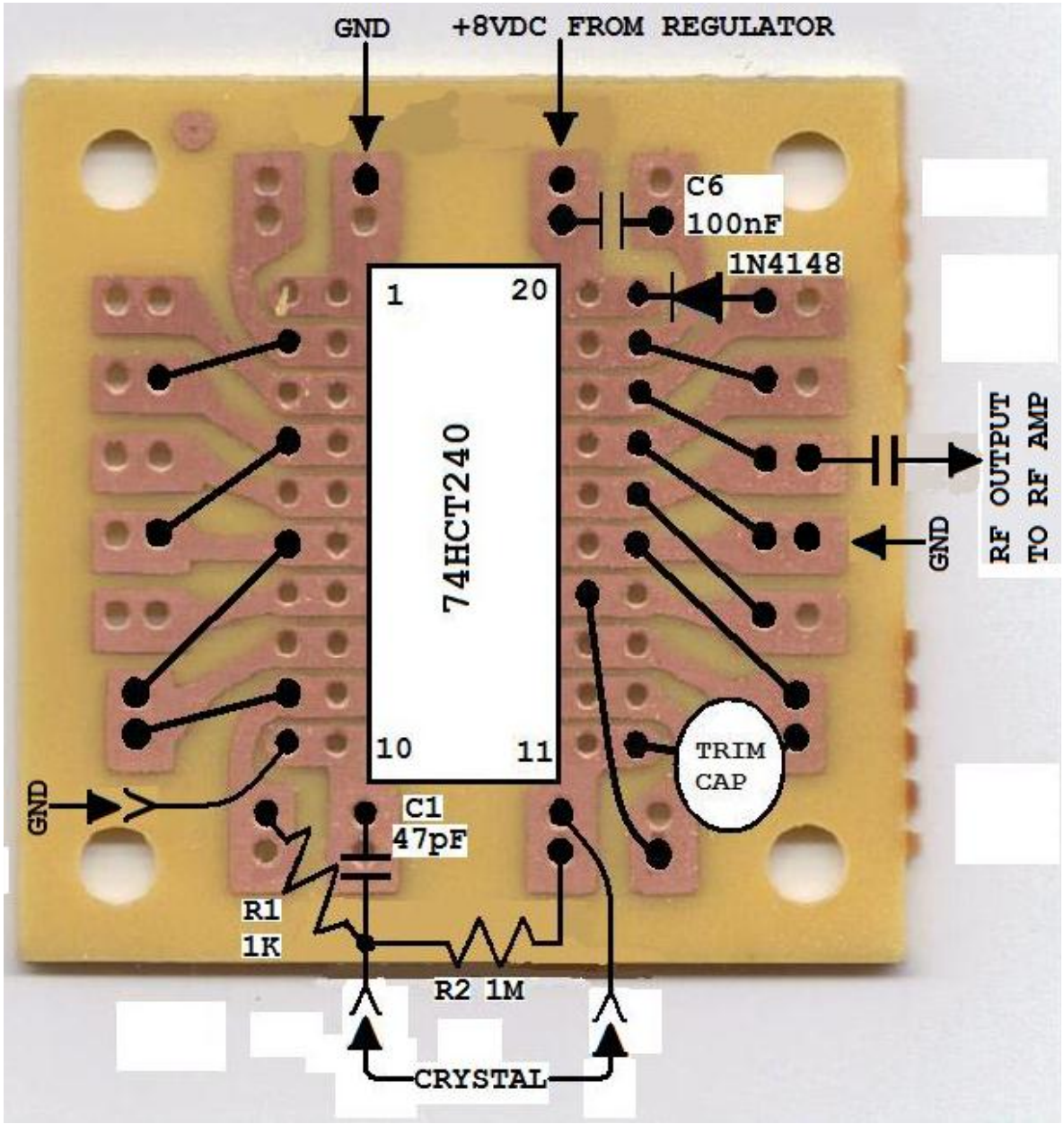
Fearless Fred Introduces: The “Franken-LULU”

They say that imitation is the sincerest form of flattery. That may just be a polite attempt to justify stealing. I don’t know. What I do know is that you are looking at six months of hard hacking, and heavy borrowing from others in this field. I have successfully rolled three of these units and now it’s time to share my version of LULU with you. She is one of the easiest high performance portable pirate transmitters that you can successfully put together - IF you will build patiently and deliberately.

As Doctor Frankenstein “borrowed” parts from many of his recently deceased neighbors to construct his beast, I have borrowed many ideas and added some of my own to construct THIS beast. My thanks go out first to a few hams, who might be horrified to realize their efforts improved the understanding of this radio pirate. LU8EHA, NA5N, N7KSB, G3CWI, PY2MG, W7ZOI, and the late W1FB are all in this group. And my contemporaries who have given me large amounts of their patient help include Dave Martin of WNKR, Boomer the Radio Animal of WKND, and Radio Anarchy of Radio Anarchy. Many thanks guys! And last but not least, I want to thank Z of Channel Z Radio for some much needed support… Z was the main trailblazer and early promoter of the LULU concept and he assured me that you CAN successfully build these rigs without an oscilloscope. He was right. Thank you Z… you DO rock! Although I am attempting to write this article at a level to help less experienced builders, please DON’T start here. If you lack RF building experience, find success with some less ambitious projects FIRST. After all, this radio stuff really IS an art… just ask any ham. And please read through the entire article at least once before starting your construction. And so we begin…

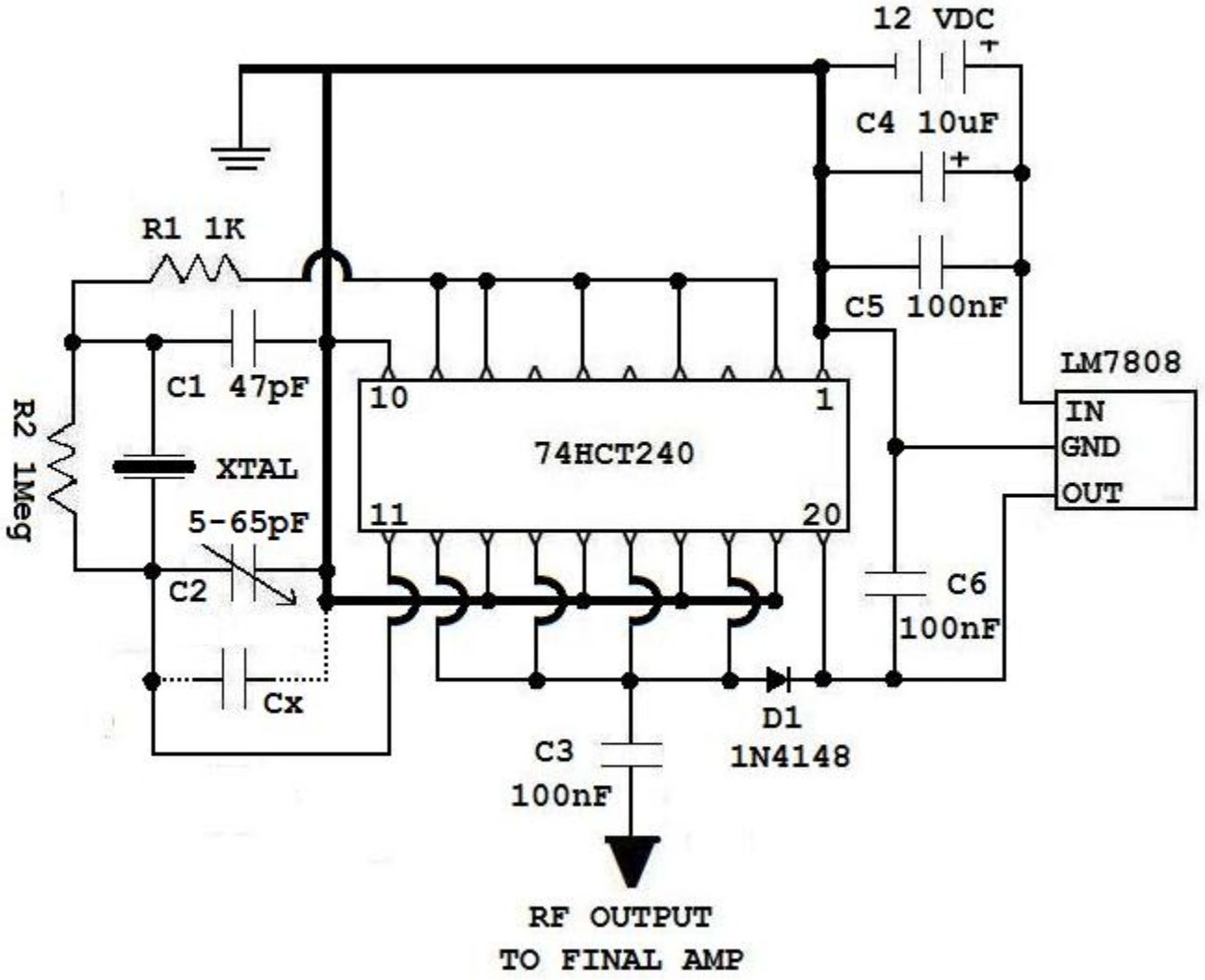
The Construction of Franken-LULU

OSCILLATOR: This is the heart of LULU and you must have a properly functioning one to build upon. I highly recommend using the ubiquitous Radio Shack breakout board method, used by Channel Z and me, and shown on the next page. To understand it, imagine that you are looking down at the components and jumpers, but that you can “see” the copper traces on the other side of the board. I also suggest being completely anal and using a VOM meter set to chirp with continuity to check and re-check for connections and shorts through every step of building this board. Your chances of success will increase dramatically if you do. Work slowly and deliberately. Mount the 8 volt regulator directly to the chassis where it will be well heatsinked. It will run quite warm. Its die is tied to the ground pin so no insulator is needed here. Connect the output capacitor and let it hang off the edge of the board for now. When complete, power up and check for your signal with a nearby receiver set to your frequency. If you find that the oscillator is sluggish, misfires, or won’t turn on at all, try soldering some extra capacitance across the trimmer. You MUST have a well-functioning unit before moving on. Be patient and do this one right. Give LULU a good heart…



Radio Shack Breakout Board

“Franken-LULU” OSCILLATOR/DRIVER



Cx soldered across the trimmer cap may be needed if the oscillator is sluggish or won’t start… try 22-47pF.

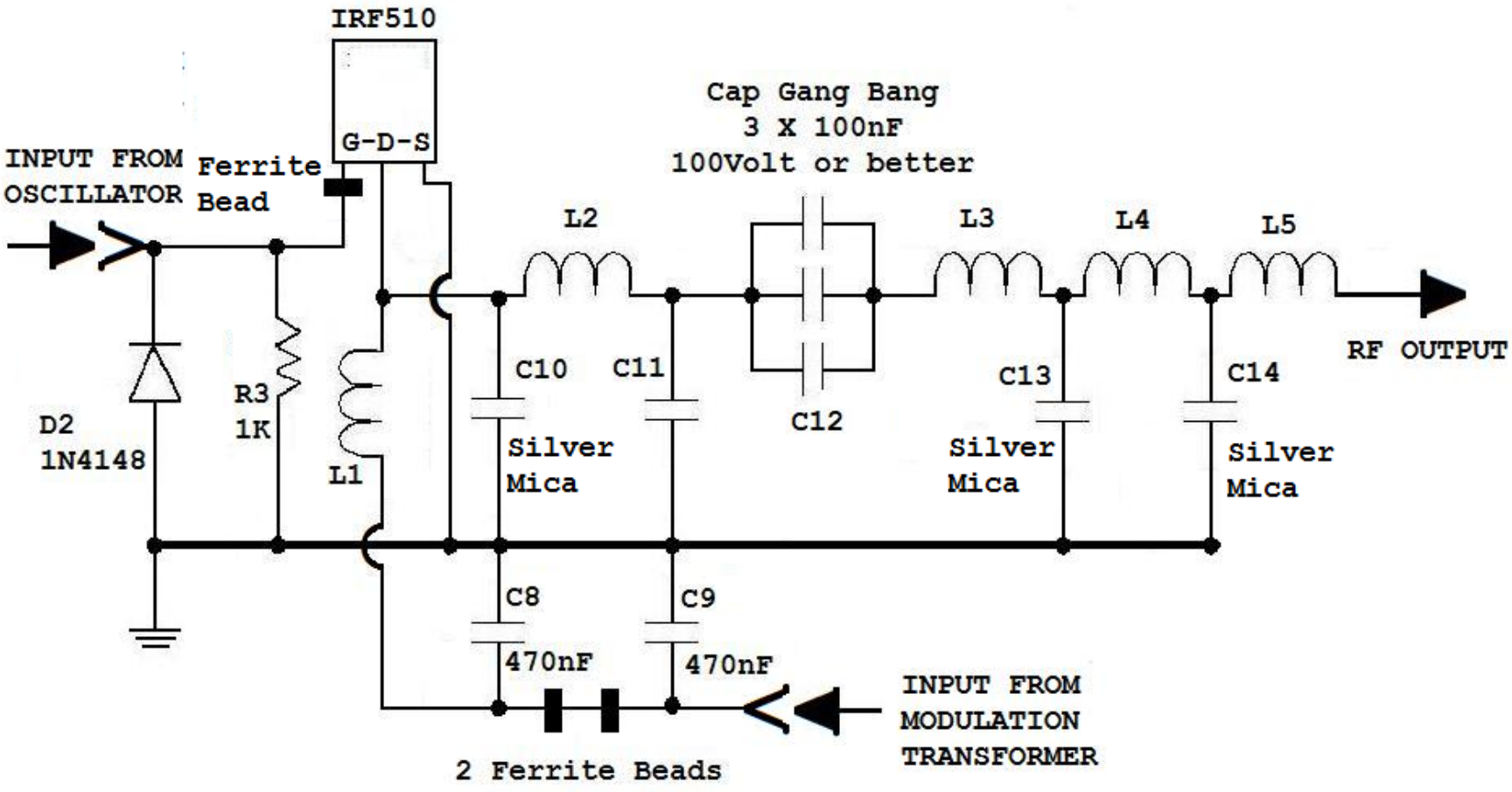
FINAL AMP: We cannot just build LULU's RF Strip; we must tweak our way in. The IRF510 was designed for use at DC and low frequency AC. We must "massage" LULU to work well in our range of interest. Mount the MOSFET (using a mica washer and nylon screw and nut), solder up the gate circuit as shown (don't forget the ferrite bead), and mount and solder L1 to the drain. L1 and C10 are the two components that allow the MOSFET to operate in Class E fashion. Class E operation is achieved at the point of maximum EFFICIENCY, which is not necessarily at the same point as maximum power output. Finger testing the MOSFET for heat is of utmost importance here. Use a jumper to connect the modulation transformer side of L1 to the +12VDC bus. Use an alligator clip to connect C10 to the drain circuit and another to connect its ground side. Run another jumper from the drain/C10 junction to your output's coax connector. Connect a dummy load and wattmeter to your output. You will now apply power for short periods and note the output that you are getting. Try several different silver mica caps (10-150pF) at C10. Find the shunt capacitor that coaxes LULU to "put out" the most. Warm is OK but hot is not. Once you are satisfied that you've found your LULU's "G-spot", then solder in C10. If the MOSFET gets even slightly hot then you haven't found it yet. Between the variations in IRF510s and the variables involved in winding L1, we will all probably end up with slightly different values of C10.

L2 and C11 form an L network that approximately matches the impedance of the MOSFET with the 50 ohm output impedance… but only approximately. With modulation, the MOSFET's instantaneous impedance can dance between 3 and 8 ohms… more than a 100% swing! How can you match that to 50 ohms? You can't. This network is just an approximation. It helps by transferring MOST of the power to the load MOST of the time. That's the best we can hope for. Solder in L2 and jumper its output to the coax connector. Use your alligator clips to try several different caps for C11. You are looking for maximum output here. I have had good results using an air variable trimmer at C11 to find the sweet spot and then using a capacitance meter to see the magic value. Find your best value for C11 and solder it in.

The remainder of the RF strip is straightforward. Radio Extreme Holland's "Capacitor Gang Bang" works well to keep the stress on the coupling caps to a minimum and is well worth the few extra cents. Most of these 10-20 watt portable transmitters are a bit light on spectral purity, which I can agree with when one is operating out and away. However, many are using these units at home most of the time. And often, home is an apartment building or trailer park. Also, LULU's oscillator is a square wave generator whose output is rich in harmonics. So, considering all this, I have replaced the traditional 3-pole Chebyshev low-pass filter with a 5-pole version. Although by no means a cure-all, it will knock down the harmonics much better. You might lose a few watts on the output, but THOSE watts will only get you the wrong kind of attention anyway.

Once you are satisfied with your RF strip, power it up and let it work for a few minutes. Keep finger testing the IRF510 every 15-20 seconds for excessive heat. Remember, warm is OK, but hot is not. If your MOSFET is too hot to put your finger on (even after 5 minutes) then you need to tweak C10 more. You are not functioning in Class E mode. If the MOSFET is getting somewhat warm after several minutes but you have good heat sinking then you can probably leave it as it is, although you are still probably not fully in class E. It's all up to you. Hey, she's YOUR LULU now, and you've brought her to life. Congratulations…

“Franken-LULU” RF STRIP



For 6.8-7.0 MHz:

L1=2.1uH (19t on T-80-2), L2=0.4uH (9t on T-50-2), L3 & L5=0.54uH (10.5 turns on T-50-2), L4=1.37uH (17t on T-50-2)

C10=27pF (nominal), C11=1000pF (nominal), C13 & C14=470pF All Caps are Silver Mica at 100 Volts or better.

CONSTRUCTION CONSIDERATIONS: As with other sassy girls, LULU likes to backtalk. The digital oscillator/driver board generates a lot of RF hash that fills the chassis with trash and gets into everything that isn't nailed down. And our toroid core being used as a modulation transformer is VERY susceptible to trash talk. My first two LULU builds had many RF issues and it took me three builds to learn how to fully tame her (that bee-yotch!). My best advice is to be anal retentive about RF construction, shielding, and grounding techniques, and build LULU's entire RF strip inside a metal enclosure. You'll save yourself a lot of aggravation if you can stop the RFI before it gets out and about.

I house my entire RF section in one of those Radio Shack $4.00 aluminum clamshells, which acts as a subsection inside my larger enclosure. This clamshell is well bonded to the enclosure by the use of MANY screws and also the coax connector on one end that mounts through the rear enclosure wall. In this way the RF output goes directly to the outside without adding to the problem. I use a double-sided blank PC board (custom cut) inside the clamshell upon which the entire RF circuit is grounded. The oscillator/driver board is mounted just above this and all three ground points are connected to the ground plane with short wires. Both voltage feeds are unbalanced (return path is through ground) and I use coax for them. The coax shield is connected ONLY to the RF circuit side, bonded to the PC board. Use the bypass caps (C4-C5, C8-C9) at these points on both voltage lead connections. The coax shield on the other end is trimmed off within an inch of its connection point and left unconnected and insulated with heat shrink. Other wiring circuits that are balanced (crystal socket leads) are fashioned as twisted pair and kept as short as possible. This is probably all you will need to do. Most troubles stop here. If you make LULU obey, she'll purr like a kitten…

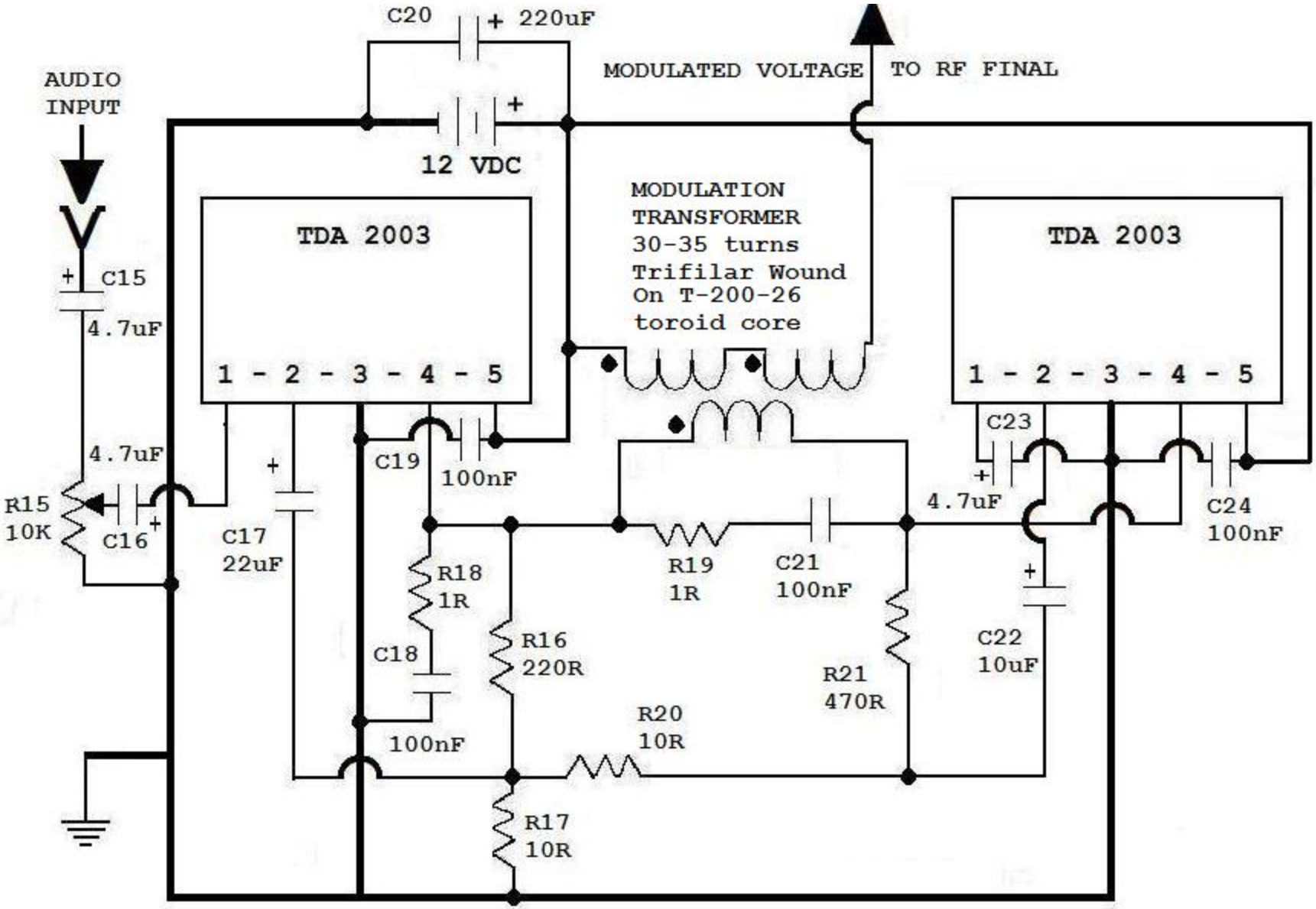
MODULATOR: I have persuaded all my LULUs to put out 16-20 watts (after the Low Pass filter). A lone TDA2003 cannot fully modulate that much RF signal. The single chip Grenade-type modulator I used in LULUs 1 and 2 gasped for air long before I pushed them hard enough to modulate LULU decently. So we are giving LULU a bridged pair modulator, capable of about 20 watts of audio. A 100% modulated 20 watt carrier is 80 watts PEP, which jiggers to about 6.7 peak amps at 12 volts, not counting inefficiencies. But perfect modulation is an unrealistic goal without good test equipment. If you choose to wind the recommended modulation transformer, your modulation will be capped at 70-75%. Why do I recommend this level? First - unless you have a decent test apparatus to set things up, you'll probably end up with an overmodulated signal. Second - if you don't have some onboard audio processing, you'll probably be splattering. Third - using this level of audio will keep your average current draw below 5 amps. This is a reasonable limit to draw from gel cells out in the boonies. Even so, I can barely get 25 clean minutes before the audio starts getting crunchy when using a single 7aH gel cell. I use two in parallel to power LULU for a 30-40 minute show. And if you're powering this at home with a 5A power supply, a larger draw will burn up its regulator in no time. And finally - it's EASIER to wind! You'll still get a nice punchy signal, but with a lot less grief. Think of this transformer as "training wheels" for LULU. And fuse her at 5 amps. Just keep in mind when operating that you possess enough modulator to blow your fuse. However you'll most assuredly be transmitting BADLY distorted audio long before it blows. Keep it sounding good in your monitor receiver, Mister!

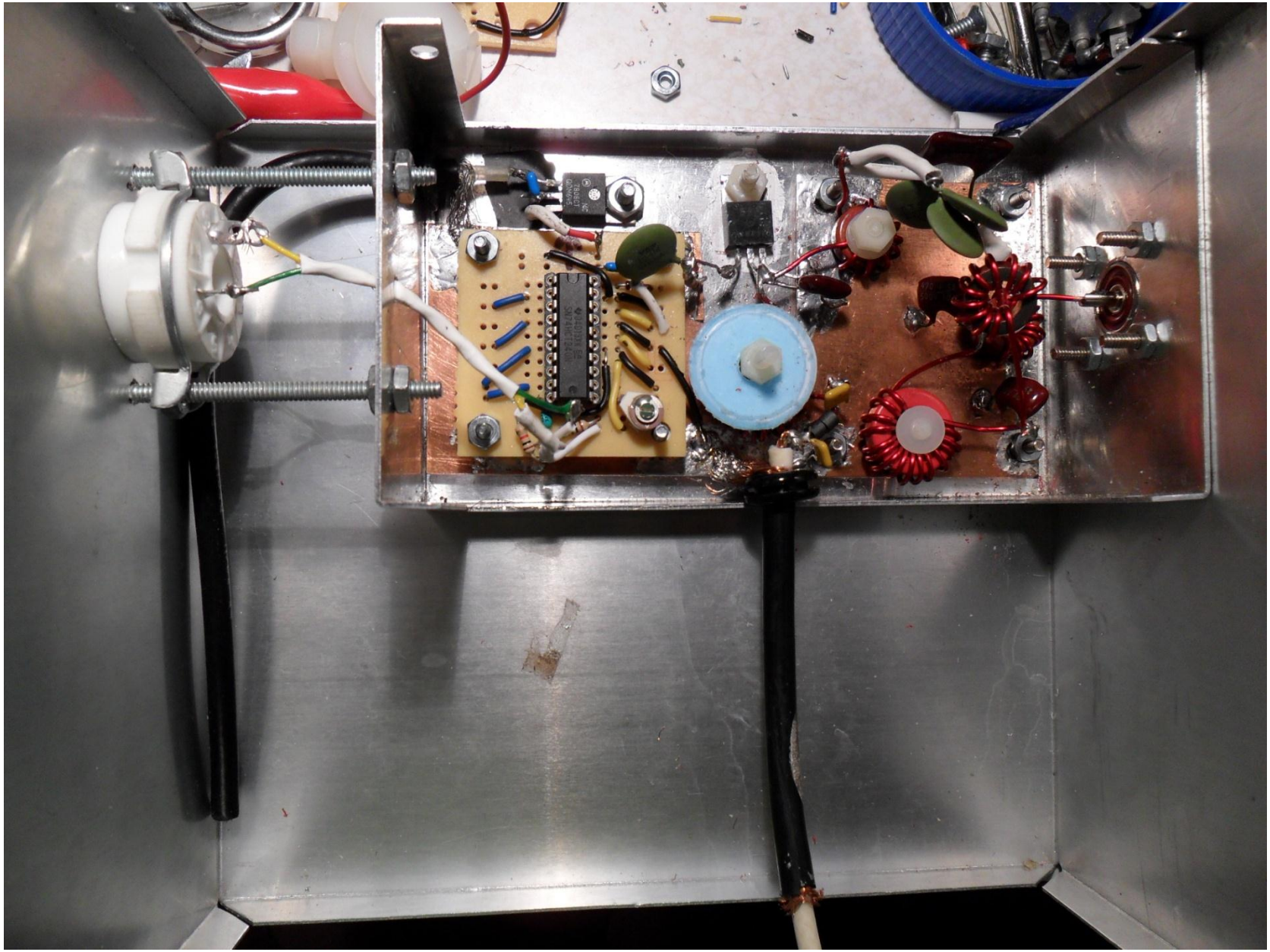
Toroids are rarely used as modulation transformers because they are a royal pain to wind. I was determined to use one with LULU because sources for small transformer iron here in the States are drying up. Interleaved cores are common; separate E and I sections are not. Although a few online tutorials explain interleaved disassembly, I have found it to be as do-able as shoving a wet noodle up a wildcat's ass. If you fancy a go at it, give it a shot. I have a feeling most will find themselves winding a toroid in short order. They're hard, but not THAT hard. My core of choice is the T-200-26, which presently can be bought from CWS Byteme for $3.00. The #26 material (yellow/white) has a flat response across the entire audio range, which is why it was picked. The 200 size toroid is a full 2 inches in diameter, and will fit the wire size and amount needed for decent inductance at audio frequencies. #18AWG wire is used for the DC winding. #20AWG is large enough for the audio winding but the DC resistance will be smaller if you use #18 there as well… your choice.

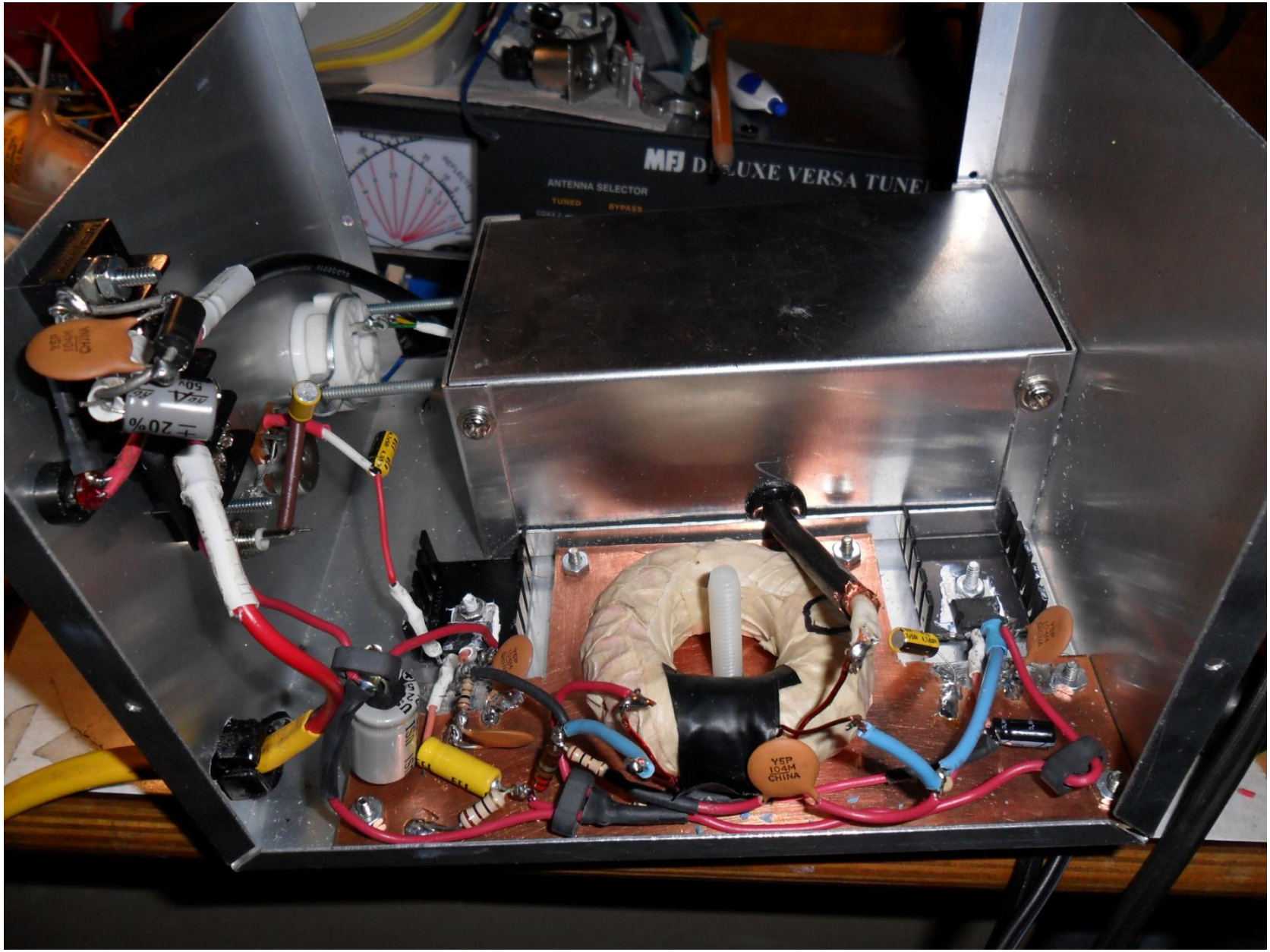
Cut three 6 foot lengths of wire. Bundle them together and tighten one end of them in a drill chuck. Secure the other ends together in a vise, locking pliers, or between your wife's teeth. With short bursts of the drill, twist the three lengths together to about 2 or 3 turns per inch. I finish up by swapping the ends to the drill and vise, then running a few more bursts. More uniform twisting happens this way. Wind the toroid with the twisted wires, trifilar style. Completely fill the INSIDE of the core, leaving no gaps there. You should be able to get 30-35 trifilar turns on. Tape the wire ends into place. Use a VOM and mark each wire 1, 2, or 3. The near end of wire 2 is connected to the far end of wire 1 and soldered. This is the DC winding center tap. Tape it up. The near end of wire 1 and the far end of wire 2 is the DC winding. Wire 3 is the audio winding. Tape the entire core with masking tape and you're done. See? Not so bad…

The bridge modulator goes together easily. The TDA 2003s will get warm. Heat sink them directly to the chassis. Their dies are at ground potential, so no special insulators are needed. Use silicone heat sink compound and metal screws to mount. I also use some cheap black radiators to facilitate heat dispersal. Keep all your leads as short as possible. Now you can test her with modulation.

If you have RF feedback problems surface (with a fully shielded RF strip), some suggestions you can try: Replace both TDA2003 supply lines with coax. Use at least RG58 or 59. Use RG174 for the audio line. Bond all shields to ground on one side only. Keep all leads as short as you can. Wrap loose wires through ferrite cores. And definitely use bypass caps to ground where the unbalanced line shields are bonded to ground. You can pop a grounded metal shield over your modulation transformer and use shielded lines in and out of it. I preemptively went to the supermarket with my little pocket rule and found a nice Chi Chi's green pepper can that fits well. Mushroom cans work but are taller than needed. I didn't need my can but I did get some great chili peppers for my burgers. Housing the RF strip in metal will probably be enough for you too, but this paragraph was included to help, should your LULU demand more.







ONWARD AND UPWARD: The one aspect of LULU not explored here is her frequency agility. Channel Z and I have both built LU variants for different frequency ranges. Although the recommended operating bandwidth here is quite narrow, it is easily changed to other ranges. In this 6800-7000 KHz version, the 5-pole low pass filter has a roll-off frequency of 7.1 MHz. One should recalculate filter values if going above 7MHz or below, say 6 MHz. The ARRL Handbook section on filters will help you jiggle the 5-pole Chebyshev low-pass calculations for the cutoff that you need. For 48M (6200-6400 KHz) operation, no major changes are required although you might find that an extra turn or two on L1 will help to get the MOSFET to run more easily in Class E mode. L2 should be alright as is. C10 and C11 will be "felt out" in the same fashion as previously described. Everything else should be fine. If one is considering a more radical change in frequency, the L Network will need recalculation. L1, L2, C10, and C11 will change. And other things should also be looked at, such as the timing constant of R3 and C3, so that it doesn't interfere with the digital pulse transmission between the oscillator and the MOSFET. The LULU oscillator/driver circuit itself has been proven to work well down at the top of the mediumwave range and up to above 15 MHz with little change in output.

Should you desire a modulation transformer upgrade; keep in mind the caveats I mentioned before. You should at least use a hard limiter or a negative peak loading scheme. And your power choices will be limited to a deep cycle marine battery, a car battery, or a LINEAR power supply (switchers can be RF noisy!) that's good for at least 8 amps continuous. I can give two suggestions on improvement. The windings ratio is most important. A quick and dirty bench check with a Wein bridge and an oscilloscope showed the present transformer capable of a 1.72: 1 voltage transformation ratio at 5 KHz. You will need more turns on the DC winding to achieve 100% modulation. From what I have found, it's easiest to bifilar wind (dual wire) the DC side (completely fill the inside of the core) and connect a center tap in the same fashion as the present transformer. Use a thin layer of masking tape. Then solo wind the audio winding overtop, adjusting the number of turns as needed. Make sure to spread all windings evenly around the entire toroid. My ear tells me that this transformer has better low end response than one wound on the (once) ubiquitous Radio Shack hash choke. However, if you desire even more, you can try using a T-200B-26 core. Or maybe better, try gluing two of the T-200-26s together. You'll have an air gap that way. But to sound right to me, I find myself REDUCING the low end gain when setting up my LULU, so I have done the better modulation thing. I haven't done the low end response thing. You're on your own there.

OK, now you have it all. I hope you will download and build this. I think you'll find that it goes together well, and performs reliably. Please experiment with this and make it better if you can. Then share your LULU with the rest of us. And by all means, cast this seed to the wind, wherever it may go. May a thousand pirate transmitters bloom…

Fearless Fred

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